Reducing the cost of solar for 300 communities throughout the country

Technical Assistance
• Online, by phone, or in-person
• Opportunity to receive a fully-funded solar expert on staff for 6-months (SolSmart Advisor)
• Free of cost to participating communities!

Rewards and Recognition
• Nationally recognized award for leading solar communities
• Three levels: Bronze, Silver, Gold
No-Cost Technical Assistance

- All communities pursuing SolSmart designation are eligible for no-cost technical assistance from national solar experts.
- Technical assistance helps governments reduce solar soft costs, spur the local solar market, and achieve SolSmart designation.

Technical Assistance Topics

<table>
<thead>
<tr>
<th>Permitting</th>
<th>Solar Rights</th>
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<tbody>
<tr>
<td>Planning &amp; Zoning</td>
<td>Utility Engagement</td>
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<tr>
<td>Inspections</td>
<td>Community Engagement</td>
</tr>
<tr>
<td>Construction Codes</td>
<td>Market Development &amp; Finance</td>
</tr>
</tbody>
</table>
Egan Waggoner

- Directed the technical training component of the New York State’s PV Trainers Network, which includes building, electrical, and fire codes as they relate to Solar PV development.
- Provides solar policy trainings for the Network and Solar Ready Vets
- Leads the Massachusetts Commercial Solar + Storage program to provide education and technical assistance to commercial interested in solar + storage procurement and Cambridge’s Building Energy Use Retrofit Program.
- Holds a Master of Science in Environmental Sciences with emphasis in Energy Systems and Water Resources from the SUNY College of Environmental Science & Forestry.
Today’s Agenda

- Introduction to solar technology [60 min]
- Identifying solar PV systems [45 min]
- Break [10 min]
- Solar PV hazards and safety [30 min]
- Identifying and disabling solar PV systems [45 min]
Acknowledgements

This presentation includes graphics, images, and schematics that have been taken from a host of various sources as well as developed specifically by the author for this presentation.

We would like to acknowledge the use of materials from the NY-Sun PV Trainers Network (PVTN), Matt Piantedosi, Tony Granato, Interstate Renewable Energy Council (IREC), the National Electrical Code (NEC), Solar ABCs, the Department of Energy (DOE), and the International Association of Electrical Inspectors (IAEI).
The views and opinions expressed in this presentation by the instructors are based upon their own experiences and understanding of the topic. They do not necessarily reflect the position of Cadmus, US DOE, or the participating states. Examples based on experiences are only examples. They should not be utilized in actual situations.

This presentation will provide an introduction solar photovoltaic technology, identifying different solar PV systems, common safety hazards and how to safely to disable a solar PV system. This course will not provide you with all the information you need to know.
Pennsylvania adheres to the 2014 NEC. This presentation has been adapted to reflect the 2014 National Electrical Code cycle and best practices and highlights some of forthcoming changes in the 2017 version.

Many changes to the most current and future versions of the NEC (2014 and 2017) have occurred due to concerns expressed by the fire fighting community with regard to solar electric systems.
2015 Pennsylvania Uniform Construction Code

At the state level, the State Building Code is based on the 2015 International Codes. This presentation has been adapted to reflect the 2015 International Codes and recommended best practices. The Building Code Council adopted amendments that have been approved by the Rules Advisory Council are as follows:

The RAC voted to adopt Chapters 2—10, 12—29 and 31—35 of the IBC of 2015
Workshop Learning Objectives

1. How to identify solar electric systems on-site

2. How to differentiate between common system types

3. How to safely disable solar PV systems
Audience Introduction

• Who here is a fire fighter or first responder?

• Other attendees: CEO, solar installers, interested citizens?

• Does anyone have a solar electric system on their home?
Today’s Agenda

• Introduction to solar technology [60 min]
• Identifying solar PV systems [45 min]
• Break [10min]
• Solar PV hazards and safety [45 min]
• Identifying and disabling solar PV systems [45 min]
Introduction to Solar Technology

Solar Photovoltaic (PV)

Solar Hot Water

Concentrated Solar Power
Introduction to Solar Technology

- Solar Photovoltaic (PV)
- Solar Hot Water
- Concentrated Solar Power
US Solar Market – annual installations

Annual Solar PV Installations in the United States

- Resi.
- Non-Resi.
- Utility
US Residential Solar PV Cost
PV Installations in DVRPC Region

Count of solar PV systems installed by county

<table>
<thead>
<tr>
<th>National Rank</th>
<th>PA</th>
<th>NJ</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>16th</td>
<td>4th</td>
</tr>
</tbody>
</table>

| Av. System Size | 7.4 kW | 7.8 kW |

| SREC Price      | $3.00  | $230.00 |

Source: SEIA, 2017; PJM, 2017; srectrade.com
Solar Job Growth in the US

After seven years of rapid job growth, solar jobs decreased in 2017. Likely reasons why:

- Solar installations kept expanding, but not as fast as in 2016
- A few big states lost jobs—but jobs went up in 29 states with emerging solar markets
- Uncertainty over the looming trade case

250,271 solar workers in the United States, as of 2017

Source: The Solar Foundation’s National Solar Jobs Census 2017
Solar Jobs in PA

In 2017, Pennsylvania had 3,848 persons employed in solar jobs across 534 different companies.
Quick Facts on Pennsylvania Solar Market

# 39 in solar jobs per capita 2017

# 19 in solar jobs across US

#22 cumulative installed solar capacity

Source: SEIA; The Solar Foundation;
Voltage

Water Analogy
Potential difference → Pressure

Electrical Concept
Potential difference → Voltage

Graphics: Egan Waggoner
Concept source: Solar Energy International
Current or Amperage

Water Analogy
Water flow rate → gallons per minute

Electrical Concept
Electron flow rate → Amps

Flow Rate
Gallons / minute

Flow Rate
Amps

Hose

Bucket

Wire

Graphics: Egan Waggoner
Concept source: Solar Energy International
Resistance

Water Analogy
Opposition to flow → friction in hoseline

Electrical Concept
Opposition to flow → Resistance

Hose with less friction

Hose with more friction

Wire with less resistance

Wire with more resistance

Graphics: Egan Waggoner
Concept source: Solar Energy International
Resistance

Water Analogy

PSI = GPM x FL

PSI = Pressure
GPM = Gallons per minute
FL = Friction loss in hoseline
Potential difference → Pressure

Energy Concept

V = I x R

V = Voltage
I = Current (Amps)
R = Resistance (Ohms)
Potential difference → Pressure
What is PV?

Photo = Light     Voltage = Electricity

The “Photovoltaic effect” is the creation of voltage or electrical current in a material upon exposure to light.

Photovoltaic Systems as defined by the National Electrical Code:
The total components and subsystems that, in combination, convert solar energy into electric energy suitable for connection to a utilization load [NEC 2014, 100]

NEC 690.4 General Requirement (A)
Photovoltaic systems shall be permitted to supply a building or other structure in addition to any other electrical supply system(s) [NEC 2014, 690.2].

NEC 2014, 100 & 690.2
How Do Solar PV Systems Work?

- Solar photovoltaics convert sunlight into electricity
- Amount of electricity directly dependent upon amount of sunlight striking the module
Inverter monitors grid voltage/power quality

- UL 1741 requires inverter to shut off within fraction of a second if power goes out of range, or completely off
- Inverter will remain off until it detects 5 minutes of continuous power
- Most PV systems today do not contain batteries or energy storage
• During production times, power goes to grid if not completely used behind the meter
  – Typically there is no onsite energy storage (today)
• At night, electricity is supplied by grid
Some Basic Terminology

Panel / Module

Cell
Some Basic Terminology

Array
Some Basic Terminology

- **Capacity / Power**: kilowatt (kW)
- **Production**: Kilowatt-hour (kWh)
System Components
Scale of Solar PV Systems

Residence
5-10 kW

Factory
1 MW+

Office
50 – 500 kW

Utility
2 MW+
Modules
Typical pitched-roof mounting

Panels are secured using an aluminum racking system.

Racking is secured to roof with lag screws drilled into structural rafters.

Mounting is designed to withstand wind loads for installation area requirements – making them very difficult to remove.
Typical flat-roof mounting
Solar PV System Types

- Roof Mount
- Ground Mount
- Parking Canopy
Solar PV System Types

- Roof Mount Commercial
- Shingles
- Ground Mount
Residential Rooftops

Costello Residence - 6 kW Grid Tied PV System

Source: Atomic Solar (North Carolina); Egan Waggoner (Lincoln, MA)
Commercial Rooftops
Commercial Rooftops
Commercial Rooftops

Middletown, CT
Shading Structures or Canopies
Ground Mount Systems
Rooftop Canopies
Pole Top Mounts
Solar Skylights
Solar Shingles

Image from PV Magazine
No guarantee you’re walking on an asphalt shingle roof
Solar Shingles
Solar Shingles
Solar Shingles
Combinations of different systems

Solar PV and Thermal Systems
Solar Thermal System

Typically 2-6 panels

Insulated piping coming from panels (as opposed to wiring) – typically copper

Solar thermal systems do not pose the same risk as solar photovoltaic systems. They typically contain a loop of water/glycol in the rooftop collectors, however there may be a scalding hazard.
Solar Thermal System

Thermal piping can be wrapped with insulation.
Solar Thermal System
Types of Electrical Current

Alternating Current

- Utility Power
- Generators

Direct Current

- PV Cells
- Batteries

Images courtesy of Durofy
1. Name three different types of solar technology

2. What’s the difference between AC and DC Current?

3. Name three locations where solar PV systems can be installed?

4. Do solar PV systems produce AC or DC electricity?
Today’s Agenda

- Introduction to solar technology [60 min]
- Identifying solar PV systems [45 min]
- Break [10 min]
- Solar PV hazards and safety [45 min]
- Identifying and disabling solar PV systems [45 min]

» Identifying solar PV systems
  - System Components
  - Understanding Schematic Drawings
    - Micro and string inverters
    - Battery back up
  - Design documentation
System Components:
Modules

1. Modules
2. Combiner Boxes/Overcurrent Protection
3. DC Disconnect Switch
4. Inverter
5. AC Disconnect Switch
6. Utility Interconnection/Overcurrent Protection
7. Utility Grid and/or Batteries
Solar Electric System Components
System Components: Modules
System Components: Modules

1. Poly
2. Mono
3. Thin film
4. Solar Laminate

Frameless
System Components: Modules

Module Specifications Sheet:
• Performance
• System Integration
• Component Materials
• Thermal Characteristics
• Warranties
## System Components: Modules

### DC Electricity

<table>
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<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Maximum power</td>
<td>$P_{\text{max}}$</td>
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<tr>
<td>Open circuit voltage</td>
<td>$V_{\text{oc}}$</td>
</tr>
<tr>
<td>Maximum power point voltage</td>
<td>$V_{\text{mpp}}$</td>
</tr>
<tr>
<td>Short circuit current</td>
<td>$I_{\text{sc}}$</td>
</tr>
<tr>
<td>Maximum power point current</td>
<td>$I_{\text{mpp}}$</td>
</tr>
<tr>
<td>Module efficiency</td>
<td>$\eta_{\text{m}}$</td>
</tr>
</tbody>
</table>

Measuring tolerance ($P_{\text{max}}$) traceable to TUV Rheinland: +/- 2% (TUV Power controlled, ID 0000039351)

<table>
<thead>
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<td>Length</td>
<td>65.95 in (1675 mm)</td>
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<tr>
<td>Width</td>
<td>39.40 in (1001 mm)</td>
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<tr>
<td>Height</td>
<td>1.30 in (33 mm)</td>
</tr>
<tr>
<td>Weight</td>
<td>39.7 lb (18.0 kg)</td>
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</table>

<table>
<thead>
<tr>
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<tbody>
<tr>
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<tr>
<td>IEC 61730</td>
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<td>UL 1703</td>
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<tr>
<td>Warranties</td>
<td></td>
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<tr>
<td>Product Warranty</td>
<td>20 years</td>
</tr>
<tr>
<td>Linear Performance Guarantee</td>
<td>25 years</td>
</tr>
</tbody>
</table>
Module Specifications Example

Specifications unique to make/model

Current-limiting power source

• Will never produce more current than their short-circuit current (Isc) rating

Strung together in series to produce greater voltage

• Similar to a DC battery

Power depends on **sun exposure** and **temperature**

Lower temperature, higher voltage

Nameplate rating on a typical PV module.
System Components: Combiner Boxes

1. Modules
2. Combiner Boxes/Overcurrent Protection
3. DC Disconnect Switch
4. Inverter
5. AC Disconnect Switch
6. Utility Interconnection/Overcurrent Protection
7. Utility Grid and/or Batteries
String Combiners

Left: Typical Residential Combiner, Right: Typical Commercial Combiner
System Components: Combiner Boxes
System Components: DC Disconnect Switches

1. Modules
2. Combiner Boxes/Overcurrent Protection
3. DC Disconnect Switch
4. Inverter
5. AC Disconnect Switch
6. Utility Interconnection/Overcurrent Protection
7. Utility Grid and/or Batteries
System Components: DC Disconnect Switches

Large Commercial or Industrial Systems have DC Disconnect Switches located on the roof top or on the side of building at ground level.
Disconnects

Disconnect switches can be integral to inverters or located remotely.
System Components: DC Disconnect Switches

Five pieces of information:

- $V_{\text{max}}$ or $V_{\text{oc}}$ (maximum system voltage)
- $V_{\text{mp}}$ (maximum power point voltage)
- $I_{\text{sc}}$ (short circuit current)
- $I_{\text{mp}}$ (maximum power point current)
- Presence of charge controller
Example of commercial system. All array conductors remain energized even with DC disconnect off.
Combiner Box with DC Disconnect
System Components: DC Disconnect Switches

Large Commercial or Industrial Systems typically have DC Disconnect Switches located on the roof top or on the side of building at ground level.
Example of commercial system.
DC combiner contains disconnect, array will remain energized.
System Components: Inverter

1. Modules
2. Combiner Boxes/Overcurrent Protection
3. DC Disconnect Switch
4. Inverter
5. AC Disconnect Switch
6. Utility Interconnection/Overcurrent Protection
7. Utility Grid and/or Batteries
System Components: Inverters

- Inverters (non-battery) convert DC power from the PV modules to AC power to match the building/grid electrical system.
- Disconnecting the AC utility power sources turns off the inverter, but DOES NOT disable the DC solar module circuit.
- 3 types of inverters:
  - *Central Inverter*
  - *String Inverter*
  - *Microinverters*
- All types stop converting power when utility power shuts down.
Central Inverter System

- Larger inverters
- Typically located remotely from array
- Most-common for large-scale ground-mount or commercial rooftop systems
• Mid-sized inverters
• Typically located adjacent to array on commercial rooftop systems
• Most-common type for residential rooftop systems, inverter will typically be located in basement or outside
Microinverter System

- Mini inverter under each module
- Most-common type for residential rooftop systems
- Typically not found on large commercial systems
- Minimum DC exposure
Utility-Interactive AC (Microinverter) System

NOTE: The grounding method shown is one of multiple allowable methods.
A GEC (grounding electrode conductor) is required only for M215-60-2LL.
It is not required for M215-60-2LL-IG.

Enphase Energy
FIELD WIRING DIAGRAM
240 VAC SINGLE PHASE
System Components: Battery String of Central Inverters

Battery Inverters convert DC power into AC power matching utility voltage and frequency to generate utility quality power. Disconnecting AC utility power turns off the inverter, but does not disable the DC solar circuit.
System Components: AC Disconnect

1. Modules
2. Combiner Boxes/Overcurrent Protection
3. DC Disconnect Switch
4. Inverter
5. AC Disconnect Switch
6. Utility Interconnection/Overcurrent Protection
7. Utility Grid and/or Batteries
System Components: AC Disconnects

AC Disconnects must in or within sight of the inverter and be marked with the following:

• Rated AC output current (Amps)
• Nominal AC voltage (Volts)

Photos courtesy of Chad Laurent and author
System Components: Utility Interconnection

1. Modules
2. Combiner Boxes/Overcurrent Protection
3. DC Disconnect Switch
4. Inverter
5. AC Disconnect Switch
6. Utility Interconnection/Overcurrent Protection
7. Utility Grid and/or Batteries
System Components: Utility Interconnection

At the location of the ground-fault protection, normally at the inverter, warning of a shock hazard (NEC 690.5[C]).

4 Main Service Disconnect

Per NEC690.14(2)

4 Breaker Panel/Pull Boxes

Main PV System Disconnect

WARNING DUAL POWER SOURCE
SECOND SOURCE IS PV SYSTEM

CAUTION: PHOTOVOLTAIC SYSTEM CIRCUIT IS BACKFEED

Per NEC 705.12(D)(4) & NEC 690.64

SOLAR DISCONNECT

CAUTION: Solar Electric System Connected

Per NEC690.33(E)(2)

Conductors at switch or circuit breakers (pull boxes) per NEC 690.4.
Main circuit breaker panel and meter per NEC 690.17, Dual power source NEC 705.12(D)(4) and Back-Fed Breakers per NEC705.22 and NEC690.64.
System Components: Understanding Schematic Drawings

1. Modules
2. Combiner Boxes/Overcurrent Protection
3. DC Disconnect Switch
4. Inverter
5. AC Disconnect Switch
6. Utility Interconnection/Overcurrent Protection
7. Utility Grid
Solar Electric System Components
Understanding Schematic Drawings: Micro Inverter or AC Module System

NEC 2014, Figure 690.1 (c)
Understanding Schematic drawings: String tied inverter systems

Image courtesy of HVCC’s TEGSMART
Understanding Schematic drawings: String tied inverter systems

Image courtesy of HVCC’s TEGSMART
System Components: Battery Backed up

1. Modules
2. Combiner Boxes/Overcurrent Protection
3. DC Disconnect Switch
4. Inverter
5. AC Disconnect Switch
6. Utility Interconnection/Overcurrent Protection
7. Batteries and Utility Grid
1. What’s the role of the inverter?

2. Name one difference between systems with storage (batteries) and those without.

3. What are the different inverter types?

4. Identify the components!
3. What are the different inverter types?
Pop quiz

3. What are the different inverter types?

- Non Battery String Inverter
- Microinverter
- Battery String Inverter

NICK FOLES
Pop quiz

4. What are these system components?

Bonus: what type?
Pop quiz

4. What are these system components?

- AC Disconnect Switch
- Solar PV Panel Bonus: thin film
- Combiner Box
- The Process
Today’s Agenda

- Introduction to solar technology [60 min]
- Identifying solar PV systems [45 min]
- Break [10 min]
- Solar PV hazards and safety [45 min]
- Identifying and disabling solar PV systems [45 min]
Today’s Agenda

- Introduction to solar technology [60 min]
- Identifying solar PV systems [45 min]
- Break [10 min]
- Solar PV hazards and safety [45 min]
- Identifying and disabling solar PV systems [45 min]

» Solar PV Hazards & Safety
  › Hazard overview/labeling
  › Site assessment
  › Protecting yourself
  › PA Code and safety recommendations
Hazard Overview & Labeling

PV System Labeling

Materials used for marking shall be reflective, weather resistant and suitable for the environment. NEC 695.11.1.1

The label shall be suitable for the environment where it is installed. NEC 110.21

At the location of the ground fault protection, namely at the inverter, warning of a shock hazard (NEC 690.5 (G)).

AC Disconnect/Breaker/
Points of Connection

PV System Labeling

Main Disconnect
Hazard Overview & Labeling
DC Raceway Label: NEC Article 690.31(G)(3)

On or inside a building

WARNING:
PHOTOVOLTAIC POWER SOURCE

Minimum 3/8” CAPS on Red

Required on all DC raceways, every 10 feet.
The utility may require specific wording on an AC disconnect. Article 690.13(B) still applies. It is important that this is not confused with the Service Disconnect.
Hazard Overview & Labeling

PV System Disconnect NEC Article 690.13(B)

The correct way: Label identifying disconnect as Solar PV disconnect.
Hazard Overview & Labeling
Disconnect Line/Load Energized NEC Article 690.17(E)

WARNING
ELECTRIC SHOCK HAZARD
DO NOT TOUCH TERMINALS.
TERMINALS ON BOTH THE LINE
AND LOAD SIDES MAY BE ENERGIZED IN THE
OPEN POSITION.
Hazard Overview & Labeling

DC Power Source NEC Article 690.53

Maintenance label showing DC system properties.
Hazard Overview & Labeling
AC Power Source NEC Article 690.54

Maintenance label showing AC system properties.
Hazard Overview & Labeling
Dual Power Sources NEC Article 705.12(D)(3)

Warning label indicating multiple sources of power present.
Hazard Overview & Labeling

“Do Not Relocate” NEC Article 705.12(D)(2)(3)(b)

Maintenance label for electrical connection in panelboard.
Hazard Overview & Labeling
AC Combiner Panel NEC Article 705.12(D)(2)(3)(c)

Maintenance label for electrical connection in panelboard.
Hazard Overview & Labeling
Service Disconnect Directory NEC Article 690.56(B)
Hazard Overview & Labeling

Inverter Directory NEC Articles 690.15(A)(4)/705.10

PHOTOVOLTAIC INVERTERS
LOCATED ON ROOF
Today’s Agenda

- Introduction to solar technology [60 min]
- Identifying solar PV systems [45 min]
- Break [10 min]
- Solar PV hazards and safety [45 min]
- Identifying and disabling solar PV systems [45 min]

» Solar PV Hazards & Safety
  › Hazard overview/labeling
  › Site assessment
  › Protecting yourself
  › PA Code and safety recommendations
Pre-plan development considerations:

• Buildings with installed solar PV systems
• Coordination with building department
• FMO Involvement in permit process?
• Maintain a record of buildings containing PV?
• Company training and walk through
• Dispatch center CAD entries
Site Assessment

• After the initial size up, consider the following
  • Is there a PV system present on the structure/property?
  • A complete 360 is important to get a look at all sides and roof
• What type of system is it?
  • PV, Thermal, integrated
Site Assessment

Sample House

Meter and AC disconnect located on “D” side

Array installed right up to ridge line with no setbacks, will not allow roof ladder hooks to sit on roof
Site Assessment

Is the system involved in a fire? If yes, what are the appropriate actions?

- Proper hose stream selection and safe distances for applying water to burning PV systems
Site Assessment

Roof Access

What do we have for roof access?
Aerial or ground ladder operations (setbacks at ridge)
Site Assessment

Ventilation

• Vertical ventilation might not be an option depending on PV system location
• Horizontal Ventilation might be the best and only choice
Site Assessment

Disconnect Location

• Where are the disconnects located?
  • Interior (garage/basement) or exterior

• Do we have access to secure the disconnects?
This is **NOT DIY work!**

Consider notification to Solar contractor for assistance

- Look for labeling
  - Information will also be on electrical/building permit

Labeling may or may not be present or legible
Site Assessment

Remote Inverter & Disconnects

- Ground-mount array, large inverter and disconnected located remotely
Site Assessment

Ground-Mount Array Near Highway

Ground-mount array near highway.
Today’s Agenda

- Introduction to solar technology [60 min]
- Identifying solar PV systems [45 min]
- Break [10 min]
- Solar PV hazards and safety [45 min]
- Identifying and disabling solar PV systems [45 min]
Protecting Yourself

• Cover panels with tarps
  • May work on small residential systems
  • Not practical for large PV systems
• Shut off all available disconnects
• Foam is not effective
• Lock Out Tag Out (LOTO) main electrical panel & system disconnects
Disconnects

**May** be effective method to de-energize system

Various system types

- Some disconnects DO NOTHING
- Can be in multiple locations
AC Microinverter System

What will happen if I shut off the main disconnect?
Conductors will be energized only under modules
All AC electrical circuits/devices will be de-energized
AC Microinverter System

What will happen if I shut off the main?

48 Vdc max

208-240 Vac

Courtesy of Enphase Energy
Central Inverter System
(Most Common)
What will happen if I shut off the main?
All AC electrical circuits/devices de-energized
AC conductors up to inverter de-energized
DC conduit inside building still energized
Rooftop DC conduit still energized

The following example assumes the PV system is connected to the main panelboard. Care should be taken, as this is not always the case and the PV system may have its own disconnect located remotely from the main breaker.
Central Inverter System
(Most Common)

What will happen if I shut off the main?

AC circuits throughout building will be de-energized if PV breaker is in main panelboard
What will happen if I shut off the main and DC disconnect?

AC circuits throughout building will be de-energized if PV breaker is in main panelboard
DC will still be energized between inverter and array
Central Inverter System
(Most Common)

What will happen if I shut off the main and DC combiner disconnect?

- **AC circuits throughout building will be de-energized if PV breaker is in main panelboard**
- **DC between inverter and combiner may be de-energized in 5 minutes**

Inverters contain capacitors!
Central Inverter System
(Most Common)

What will happen if I shut off the main, DC, and DC combiner disconnects?

*AC circuits throughout building will be de-energized if PV breaker is in main panelboard*

*All DC conductors between inverter and DC combiner will be de-energized*

*Array conductors still energized*
Example of commercial system. All array conductors remain energized even with DC disconnect off.
Combiner Box with DC Disconnect
Combiner Boxes with DC Disconnects
At Watertown DPW
Prior to the 2011 Code, combiner boxes were not required to have disconnects.
Combiner Boxes

Opening fuseholders under load is dangerous
Arcing hazard

Inverter or DC disconnect **MUST be shut down** before fuseholders are opened

Inverter will shut down automatically if main breaker is off
If there is a fault in the DC wiring (modules burning, etc.), current will still flow to ground and a hazard may still exist when opening fuseholders
Example of commercial system.
No rooftop DC disconnects, array conductors remain energized.
Example of commercial system. DC combiner contains disconnect, array will remain energized.
Ground-mount array with DC combiner/disconnect. Array conductors remain energized if disconnect is opened “off.”
Location of inverter/disconnect.
All other array conductors will remain energized when modules are exposed to light.
Rapid Shutdown of PV Systems on Buildings

Applies to all buildings permitted to the 2014 edition of the NEC
PV system circuits on or in buildings shall include a rapid shutdown function:
   690.12(1) through (5)...
About Article 690.12
2014 National Electrical Code

Intended to protect first responders

Original 2014 proposal:
  Disconnect power directly under array
    Module-level shutdown

Compromise:
  Combiner-level shutdown
Rapid Shutdown of PV Systems on Buildings
2014 NEC Article 690.12

690.12(1)
More than 10’ from an array
More than 5’ inside a building
Rapid Shutdown of PV Systems on Buildings
2014 NEC Article 690.12

690.12(2)

Within 10 seconds
  Under 30 Volts
  240 Volt-Amps (Watts)

A typical module:
  ~250 Watts
  ~30 Volts

690.12(3)

Measured between:
  Any 2 conductors
  Any conductor and ground

Source: UL.com
Rapid Shutdown of PV Systems on Buildings
2014 NEC Article 690.12

690.12(4)  
Labeled per 690.56(C)

PHOTOVOLTAIC SYSTEM EQUIPPED WITH RAPID SHUTDOWN

• Minimum 3/8” CAPS
• White on Red
• Reflective
690.12(5)

“Equipment that performs the rapid shutdown shall be listed and identified.”
About Article 690.12

Open-ended gray areas:

• Location of “rapid shutdown initiation method”
• Maximum number of switches
About Article 690.12

Considerations:

• Disconnect power within 10 seconds
• Inverters can store a charge for up to 5 minutes (UL 1741)
About Article 690.12

What complies:

- Microinverters
- AC modules
- DC-to-DC Optimizers/Converters
  - May or may not depending on the model
About Article 690.12

What complies:
Exterior string inverters if either:
• Located within 10 feet of array
• Inside building within 5 feet

“Contactor” or “Shunt Trip” Combiner Boxes/Disconnects
• Must be listed for “Rapid Shutdown” as a system

Many considerations & variations for full system compliance
• Plans should be discussed with AHJ prior to installation
Extinguishing a PV Fire and Hose Stream

Is water a good idea?
Firefighter Safety and Photovoltaic Installations Research Project

UL Findings – Hose Stream

Voltage of PV system
Nozzle diameter
Pattern of water spray
Distance between nozzle and live components
Conductivity of water
UL Findings – Hose Stream

**Smooth Bore**
- Up to 1.25”

**Adjustable**
- Solid stream to wide fog

**UL Recommendations:**
- At least 20’ away for smooth bore
- At least 10° angle for adjustable
  - UL 401 Standard, 30° min cone angle
    - “Portable Spray Hose Nozzles for Fire-Protection Service”
Hose Stream

Test with pond water and **smooth bore nozzle**

<table>
<thead>
<tr>
<th>Distance</th>
<th>Smooth bore nozzle size</th>
<th>Pressure PSI</th>
<th>Voltage DC Volts</th>
<th>Leakage current Milliamps</th>
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</thead>
<tbody>
<tr>
<td>10</td>
<td>1 inch</td>
<td>21</td>
<td>1000</td>
<td>5.7</td>
</tr>
<tr>
<td>10</td>
<td>1 inch</td>
<td>21</td>
<td>600</td>
<td>3.2</td>
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<tr>
<td>10</td>
<td>1 inch</td>
<td>21</td>
<td>300</td>
<td>1.6</td>
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<td>50</td>
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<tr>
<td>20</td>
<td>1 inch</td>
<td>23</td>
<td>1000</td>
<td>1.5</td>
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</table>

<table>
<thead>
<tr>
<th>Leakage current Milliamps</th>
<th>Safe</th>
<th>Perception</th>
<th>Lock On</th>
<th>Electrocution</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 2 mA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.1 - 40 mA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40.1 - 240 mA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 240 MA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: UL.com
Hose Stream

Test with pond water and narrow fog pattern at 5’
Zero leakage current at 1000 Volts

Source: UL.com
In conclusion UL recommends:

- At least 20’ away for smooth bore
- At least 10° angle for adjustable
  - UL 401 Standard, 30° min cone angle
    - “Portable Spray Hose Nozzles for Fire-Protection Service”
Personal Protective Equipment (PPE)

Are we safe from all hazards?
Personal Protective Equipment (PPE)

UL tested firefighter gloves and boots to determine electrical insulating properties.

Various tests performed on items:

- New
- Soiled
- Wet
- Worn
Personal Protective Equipment (PPE)

Typical electrician rubber gloves evaluated to ASTM D 120, and must be worn with leather protectors

Firefighter boots and gloves typically tested to NFPA 1971
  • Boots require similar test to electrician boots
  • No electrical requirements for gloves
### Personal Protective Equipment (PPE)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Soiled</th>
<th>Wetted Outside</th>
<th>Wetted Inside</th>
<th>Measured milliAmps, DC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>50 Vdc</td>
</tr>
<tr>
<td>1</td>
<td>no</td>
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<td>0</td>
</tr>
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<td>yes</td>
<td>78</td>
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## Personal Protective Equipment (PPE)

<table>
<thead>
<tr>
<th>Boot Sample</th>
<th>New</th>
<th>50% Toe</th>
<th>100% Toe</th>
<th>Hole in Bottom</th>
<th>Measured milliAmps, DC$^4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
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</tr>
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</table>

### Boot Aged$^1$

<table>
<thead>
<tr>
<th>Boot Sample</th>
<th>New</th>
<th>50% Toe</th>
<th>100% Toe</th>
<th>Hole in Bottom</th>
<th>Measured milliAmps, DC$^4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>3</td>
<td>X</td>
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</table>

### Boot Aged$^2$

<table>
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<tr>
<th>Boot Sample</th>
<th>New</th>
<th>50% Toe</th>
<th>100% Toe</th>
<th>Hole in Bottom</th>
<th>Measured milliAmps, DC$^4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>X</td>
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<tr>
<td>3</td>
<td>X</td>
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</tr>
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</table>

### Boot Bottom$^3$

<table>
<thead>
<tr>
<th>Boot Sample</th>
<th>New</th>
<th>50% Toe</th>
<th>100% Toe</th>
<th>Hole in Bottom</th>
<th>Measured milliAmps, DC$^4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Measured milliAmps, DC$^4$

- 50 Vdc: 0
- 300 Vdc: 6, 13, 4, 30, 26
- 600 Vdc: 45, 108, 78, 184, >250
- 1000 Vdc: 94, >250, 135, >250, >250

### Safety Rating
- Safe
- Perception
- Lock On
- Electrocution
Alternative Light Sources

- Artificial light sources
  - In most cases, artificial light produced enough power to energize PV to a dangerous level
- Light from fire
  - UL concluded dangerous voltages were present at each distance
- Moonlight
  - UL concluded dangerous voltages were **not** present in moonlight conditions with no other ambient light present
  - From 20 minutes after sunset to 20 minutes before sunrise
  - Caution should still be used as equipment can vary
Electrical Hazards
Cutting Live Conductors

UL tested effects of cutting conductors and conduit with live hazardous DC voltages:

- Uninsulated cable cutter
- Fiberglass handle axe
- Rotary saw
- Chain saw

Source: UL.com
Damaged Models/Equipment

UL tested two types of damage:

• Physical with axe or other tool
• Damage from fire
Damaged Models/Equipment

Physical damage test with glass frame modules:
Axe or other tool was grounded, similar to wire cut test
Arcing and flames occurred

Source: UL.com
Damaged Models/Equipment

UL tested many modules after exposure to fire:

Figure 101 Open flames on roof
Figure 102 Modules sagging
Figure 103 Roof and modules collapsing
Figure 104 Roof collapsed - fire extinguished

Source: UL.com
Damaged Models/Equipment

After fire:
   Array reconstructed

Figure 113  Post fire, front surface

Figure 114  Post fire, back surface

Source: UL.com
Damaged Models/Equipment

Every module tested

Figure 117 - Module D1 – badly burnt on backside, but functional and producing full voltage

Source: UL.com
Damaged Models/Equipment

60% of modules still produced full power
Only 25% completely destroyed → no power

Figure 112  Roof diagram after fire: X = no power, dashed-X = partial power
Shock Hazards

*During and Post-Fire...*
Shock Hazards

UL identified many shock hazards present

- Bare conductors
- Energized racking
- Energized metal roof
Night time fires involving PV systems

Use caution during overhaul as PV wiring can be hidden in attics and walls

Modules can produce dangerous voltage from scene lighting

PV modules will become energized during daylight hours
Other Hazards

*Beyond the wires...*
Inhalation hazards (This is nasty smoke)

You MUST use SCBA when dealing with fire involving PV arrays

- Treat it like the Hazmat call it is

PV cells can produce three main chemicals when burning:

- Cadmium Telluride (usually on commercial or utility scale installations)
  - Carcinogenic
- Gallium Arsenide
  - Highly toxic and carcinogenic
- Phosphorous
  - The worst of the three
  - Lethal dose is 50 mg
In addition to electrical hazards

- Broken glass
- Falling modules
- Tripping and slipping hazards can be amplified on pitched roofs
- Insects and rodents
Trip/Slip Hazards

Be aware of conduit and conductors flat rooftops.

Poor wire management leads to additional hazards.
Trip/Slip Hazards

Array covered entirely in snow.

Rooftop conduits buried in snow.
In Conclusion

• Work with building department to determine locations of all PV systems on buildings in your district

• Familiarize yourself with the systems on large public buildings, installers/inspector will often welcome a tour to learn the hazards

• Always treat all conductors as live until proven otherwise by a qualified person
Currently there have been no United States fire service related deaths resulting from incidents involving Photovoltaic systems.

Through education, training, preplanning and a solid partnership with the PV industry our goal is to keep this number at ZERO.
Resources

- UL Firefighter Safety and PV Course
- IREC Online Training for Firefighters
- Fire Fighter Safety and Emergency Response for Solar Power Systems
- Rooftop Solar PV & Firefighter Safety
- Free access to 2015 I-Codes
Thank you!

Egan Waggoner
Senior Analyst
Cadmus
egan.waggoner@cadmusgroup.com
Date of fire: 3/27/12
Contractors finishing 100 panel PV system installation
Rooftop inverter arced, shocked several workers and started a fire in several junction boxes
Contractors disconnected sections to allow FF’s to extinguish fires. Dry chemical extinguishers were used each time a box was taken offline. Almost 2 hours until all power was cut.
• Date of fire: February 11, 2016
• Macy’s Department store, East Brunswick Square mall
• Fire reported at approximately 10:00 am
• Incident Commander reports fire in Solar panels on roof
• 2nd Alarm transmitted
• Access to roof made and disconnects utilized
• Aerial ladder used with fog pattern to extinguish fire
• Fire contained to Solar panels, overhaul withheld until contractor arrived on scene (1 hour from notification)
• Approximately 30 modules involved
• Department had no formal training in Safety around solar panels